Tec Tracking Efficiency in Run 4

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1. Introduction to Tec Tracking

Tec tracking uses Hough Transform method to find tracks. The Hough Transform is a standard method that allows pattern recognition in a transformed parameter space.

Main idea is that TEC tracks are lines, and each line has its unique slope and intercept (or, alternatively, other pairs of variables could be used). If one draws a line through a pair of Tec hits, then slope and intercept for this line will be always the same for hit pairs belonging to the same track. Lines drawn through hit pairs taken from different tracks will be more or less randomly distributed in slope/intercept space, as is shown in the plot below. Slope and intercept are not the best variables, since they are not bound. General idea of Hough Transform is illustrated in Fig.1.
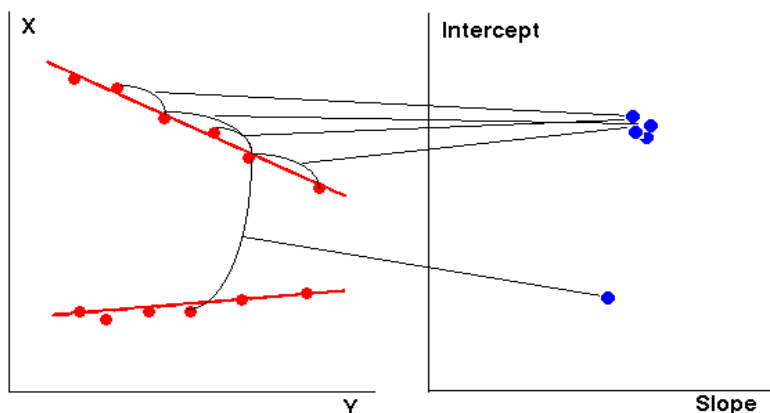

Fig. 1

We found that the best choice of the variables for Hough Transform is the same as is used for the Drift Chamber - polar angle Phi at the intersection of the track with a reference circle, and bending angle Alpha between the track and reference line (see Fig.2). Alpha angle is inversely proportional to the track momentum. Without magnrtic field Alpha is 0.
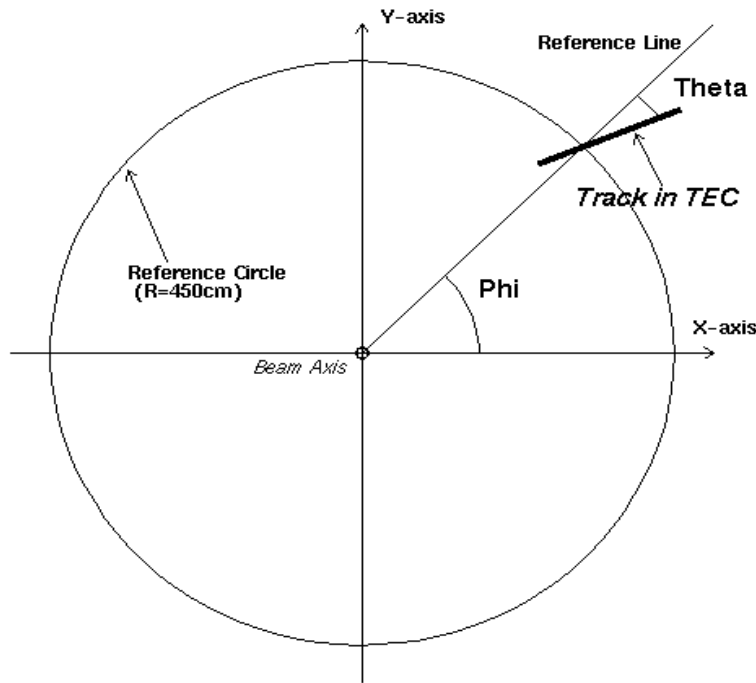
Fig. 2

Since all tracks are lines, then, if we consider all possible combinations of hits in TEC, and calculate Phi and Alpha for them, hit pairs from the same track will have the same Phi and Alpha, while all other combinations will be more or less randomly distributed in Phi-Alpha space. This will cause peaks to appear in two-dimensional plot Phi-vs-Alpha, each peak corresponding to a track.

Tracking is done in *mTecHoughTrackModule* class, separately for each side of each sector. No tracking is done between sectors.

For each TEC wire, 80 charge samples are read out using FADCs. Each sample is measured at a time shifted by ¼ of RHIC clock. These charge samples are called time bins, or hits.

Since possible number of hit pairs is very large (millions, or even tens of millions for central events) only some limited number of hit pairs is used in the Hough Transform. These pairs are randomly selected among all possible pairs. This is done to reduce CPU time.

First, number of hit pairs to be used is determined as Nhits*Nhits/Statistics1, where Nhits is total number of hits in the event. **Statistics1** is a tracking parameter with default value of 4000 (for run4 AuAu). If number of pairs is calculated to be less than 10k or greater than 500k, it is set to these limits.

For each active TEC plane (there are 6 planes in a sector, and the list of active planes is kept in the database) all hits are stored in two arrays.

The first array is used for the Hough Transform, and time bins (hits) in this array are usually summed up (default value of tracking parameter **Rebin** is 4) to make the number of possible hit pairs smaller. Rebinned hits are put in this array only if sum of ADC values from all time bins is larger than **clPar[5]** = BinThreshold (default = 4).

The second array keeps hits for association with tracks. This array is never rebinned and hits are put in this array if their ADC is larger than **LowThreshold** parameter (default = 2).

Next, two random hits from two different planes are taken from the first array, and Phi and Alpha are calculated for a line joining these two hits. A two-dimensional histogram Phi vs Alpha is filled. Hit pairs are selected randomly from all Tec hits in the same sector side.

Bin size of the two-dimensional Phi-vs-Alpha histogram is choosen in such way, that hit combinations from the same track have Alpha and Phi within 2-3 channels. This enables to determine tracks Phi and Alpha with good accuracy.

The code then looks for clusters (peaks) in this two-dimensional histogram. A cluster is defined as a group of adjacent bins with amplitudes greater than **clPar[0]** (default = 0.05) fraction of the maximum bin in the histogram. The code calculates total amplitude of the cluster (sums up all bins belonging to a cluster). If this amplitude is greater than some threshold (**clPar[1]**, default = 0.08 of the maximum), the peak is accepted as a candidate for a track.

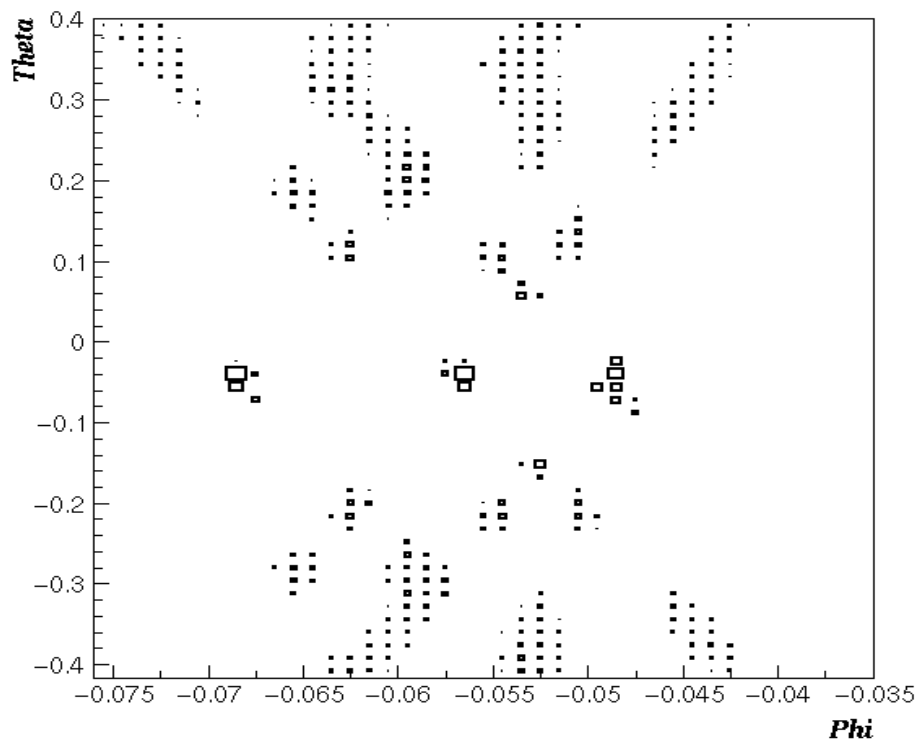Typically, clusters before amplitude cuts look like this (example for 3 tracks):

Fig. 3
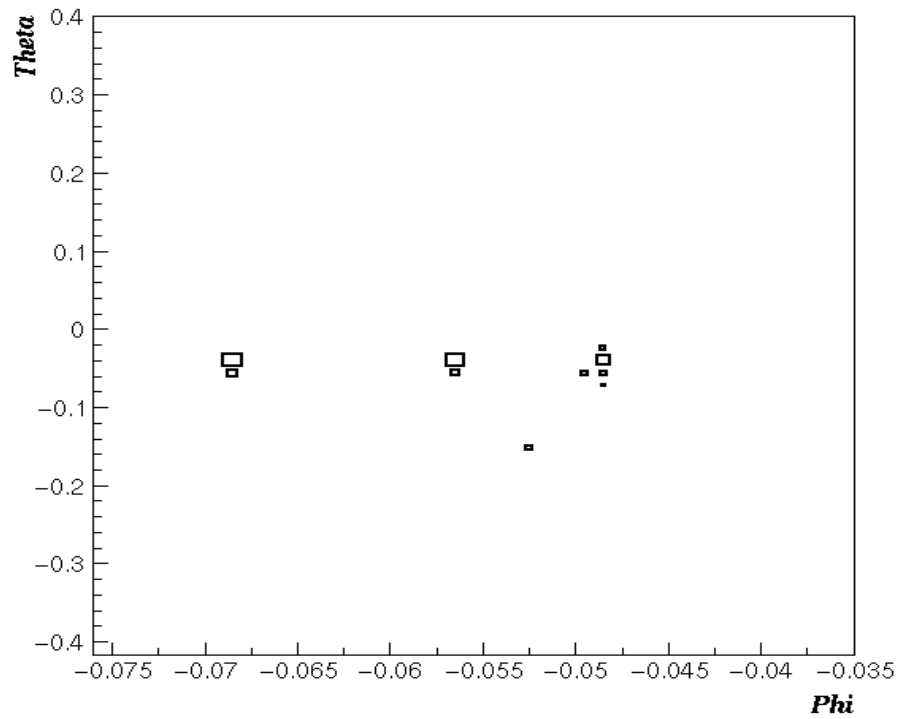
and after the cuts like this:

Fig. 4

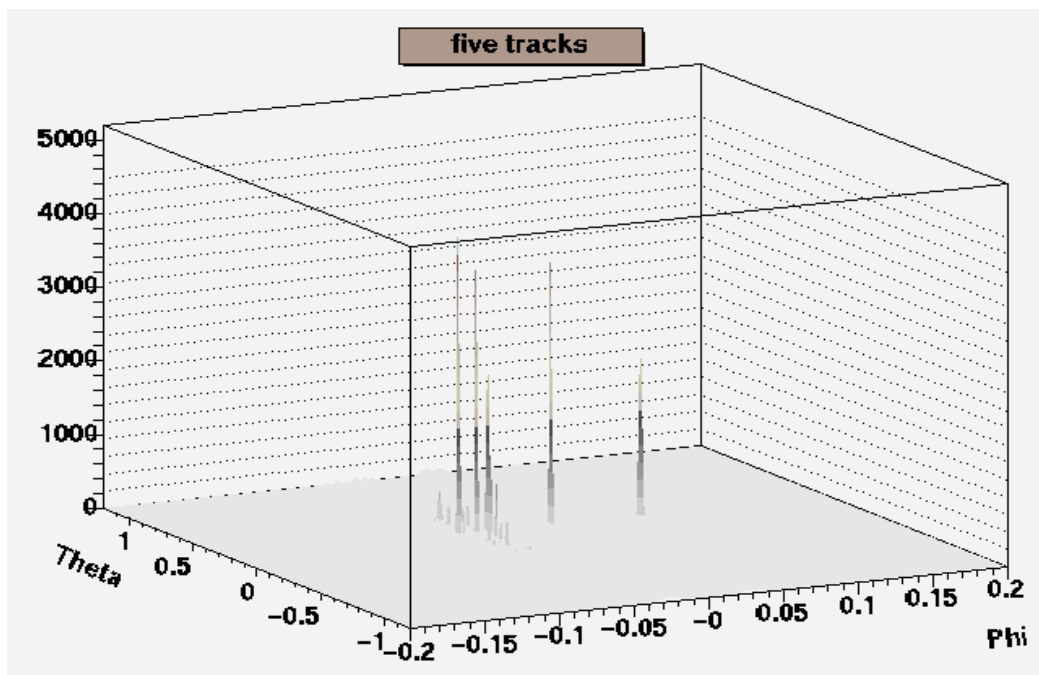Here is a three-dimensional look at Phi-Alpha distribution for 5 tracks:

Fig. 5

The following plots shows an example of tracking a isimulated Hijing event in one side of one sector:
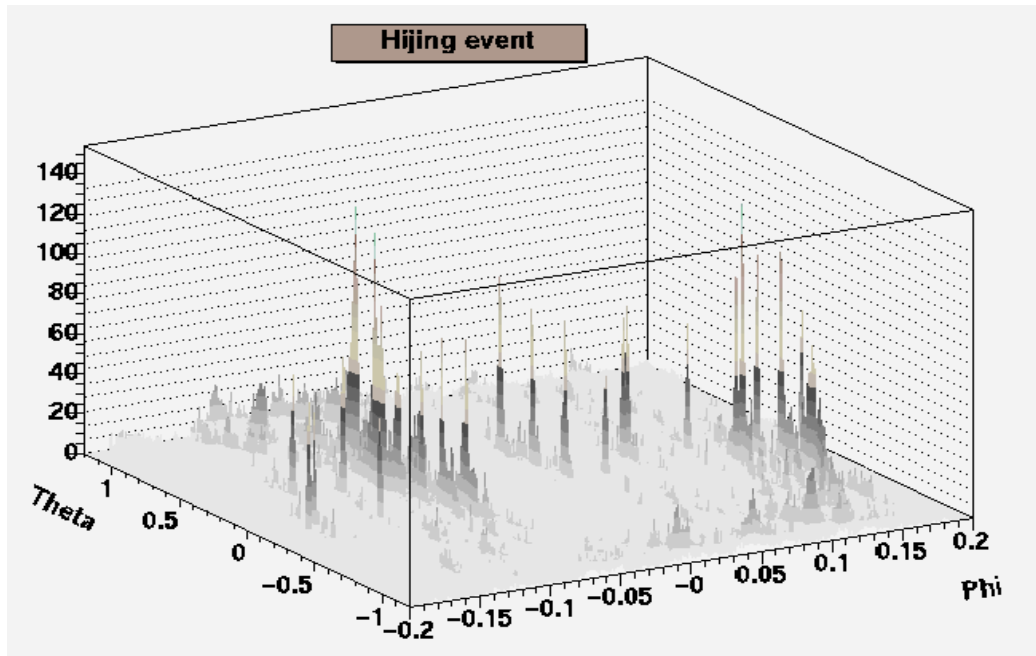

Fig. 6

Peaks (clusters) in two-dimentional Phi-vs-Alpha histogram are considered as track candidates.

Given the slope and intercept of the track candidate, the code searches for all hits associated with this track candidate. If a hit is within **Dist0** distance from a track (default 0.26cm), this hit is considered as associated with the track. A hit can be associated with several tracks.

After hit association, tracks are re-fitted using associated hits (this improves space resolution), and several cuts are applied:

1) a cut on angle of incidence, to reject ghost tracks (this cut will also reject real tracks with momentum < 100 MeV/c). (**angLim** <0.6).
2) a cut on total number of associated hits (**minbins** >74).
3) a cut on number of planes with at least 4 associated hits (**minPlanes** >2).
4) a cut on effective number of hits (**clPar[2]**, default = 1.5). Since hits can be associated with more than one track, we calculate effective number of hits by assigning weight to hits. Weight=1 is assigned to hits which are associated with only one track, weight=1/2 for tracks shared by 2 tracks, 1/3 for tracks shared by 3 tracks, etc. Effective number of hits should be larger than the total number of hits divided by clPar[2].

Tracks which pass all cuts are used to fill TecOutV1 object. After tracking is finished, hits and tracks from TecOutV1 are copied to TecOut and TecHitOut objects, which are written out to the output file. This is done to save disk space. The hit class in the TecOutV1 object contains hit coordinates and calibrated charge. Since coordinates and calibrated charge can be calculated if geometry and calibration constants are known, the hits written out to file (in TecHitOut object) do not have coordinates and calibrated charge.

2. Tracking Parameters

Statistics1 (default=4000): Number of hit pairs used in Hough Transform is determined as Nhits*Nhits/Statistics1, where Nhits is the total number of hits in an event, (typically from 2k to 30k in run4 AuAu). Number of pairs can not be larger than 500k and smaller than 10k. Tracking efficiency vs this parameter is shown in fig.13.

minbins (default = 74): Number of hits per track must be larger than this number in order for the track to be accepted. Tracking efficiency vs this parameter is shown in fig.10.

minPlanes (default = 2): Track must have hits in more than minPlanes planes to be accepted.

algorithm (default=1): Select clustering algothithm. There is no significant difference in tracking efficiency between two algorithms. Algorithm==1 means that a hitogram bin has 8 possible neighbours (4 touching it by side, and 4 touching it at corners). Agorithm==0 means that there are only 4 possible neighbours (touching the bin by sides).

angLim (default = 0.6): Tracks with Alpha greater than angLim are rejected (very low momentum tracks, ghosts or rescattered tracks).

clPar[0] (default = 0.05): Cluster finding cut. Hough Transform histogram bins are used for cluster (peak) finding only if they are higher than this fraction of the maximum bin in the histogram.

clPar[1] (default = 0.08): Cluster finding cut. If histogram bin is higher than this fraction of the maximum bin, and is higher than all its neighbours, it is considered as a maximum (a peak). Tracking efficiency vs clPar[0] and clPar[1] is shown in fig.14 and fig.15.

clPar[2] (default = 1.5): Hit sharing cut. For each track total number of hits (Ntot) is calculated. Also, a weighted number of hits (Nweighted) is calculated, with weight equal to ½ if hit is shared by 2 tracks, 1/3 if hit is shared by 3 tracks, etc. Track is accepted if Ntot/Nweighted > clPar[2].

clPar[3] (default = 0.08): Peaks in Hough Transform histogram are accepted as track candidates only if their amplitude is larger than clPar[3] times highets peak in the Hough Transform histogram. Tracking efficiency vs this parameter is shown in fig.11.

clPar[4] (default = 99): Cluster splitting cut. Not used at present, no cluster splitting.

clPar[5] (default = 4): Only hits with ADC value larger than this parameter are used in Hough Transform. Tracing efficiency vs this parameter is shown in fig.10.

Dist0 (default=0.26): Distance from the track to a TEC time bin required for the bin to be associated with the track. In centimeters.

LowThreshold (default = 2): Only hits with ADC value larger than LowThreshold are used in hit/track association.

Rebin (default = 4): If Rebin is greater than 1, several adjacent time bins of the same wire are summed up to form one hit, which is then used for filling Hough Transform histogram. This is done to reduce total number of possible hit pairs.

Radius0 (default = 450.): Track Phi and Alpha are calculated at the intersection of the

track with this reference radius. The default value 450cm is set as TECREFERENCERADIUS constant in *TecBasicObject.hh* file.

3. Tracking Efficiency Calculation

Tec tracking efficiency is calculated by embedding single simulated particles in real events, doing tracking for the merged events and then trying to find embedded particle among the tracks found in the merged event.

Simulation is done using, for each plane, gas gain value determined during calibration of the run4 AuAu data.

A particle is considered to be found if most of its hits are coming from the Geant particle (Geant particle is "dominant contributor"), and the displacement of track coordinates is less than 3 sigmas compared to coordinates before merging.

Electron tracking efficiency for minimum bias AuAu events was determined to be 90.1%, and pion tracking efficiency 81.0%.

The code for efficiency evaluation is in *offline/packages/tec/mTecTrackEvalModule* class and *offline/analysis/AnaFun4All/TecAnalysis* class.

4. Tracking Efficiency Results

All plots in this section were made by merging simulated single particles with events from run # 127297. Simulation was done with gas gains determined for sector 1, south side, for the same run.

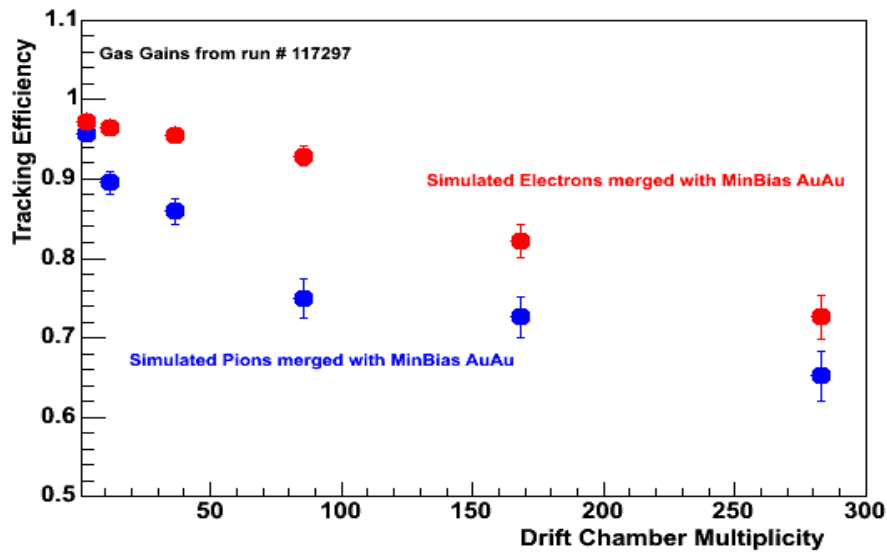Fig.7 shows Tec tracking efficiency as a function of number of Drift Chamber tracks (centrality).

Fig. 7

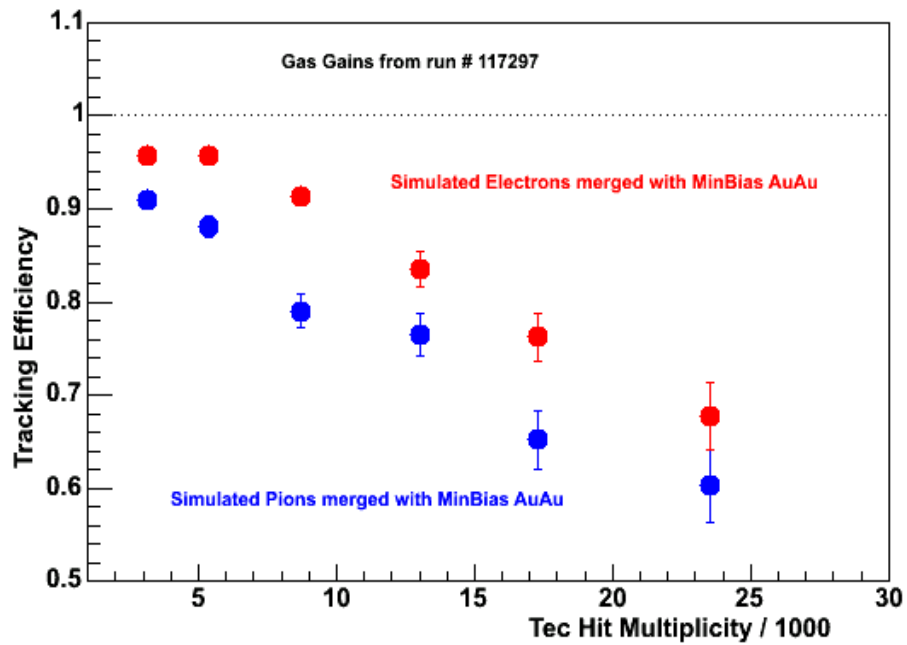Fig.8 shows tracking efficiency vs total number of Tec hits in an event:

Fig. 8

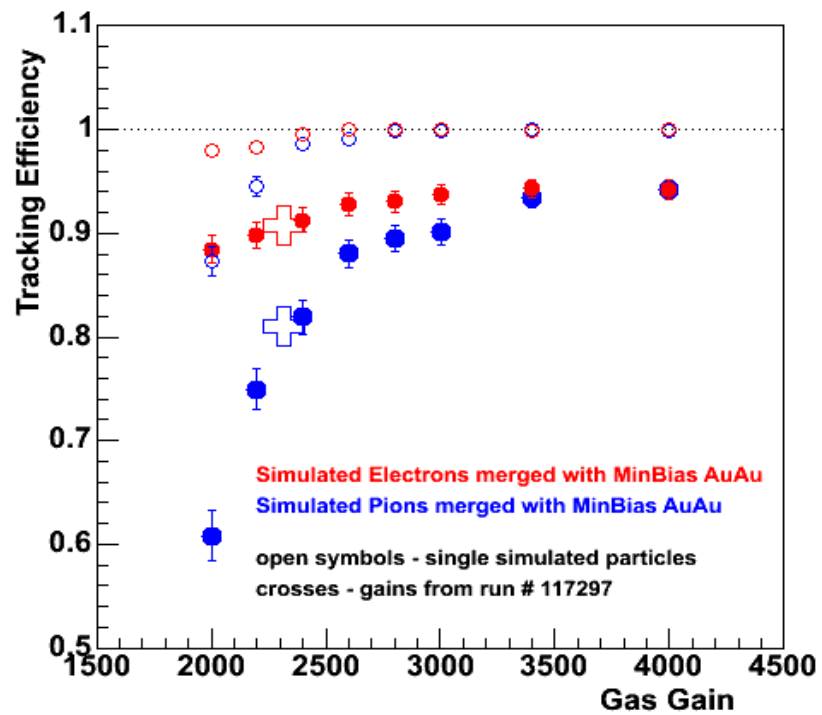Fig.9 shows tracking efficiency vs gas gain:

Fig. 9

5. Tracking efficiency vs various tracking parameters

Fig.10 shows tracking efficiency vs **minbins** parameter:
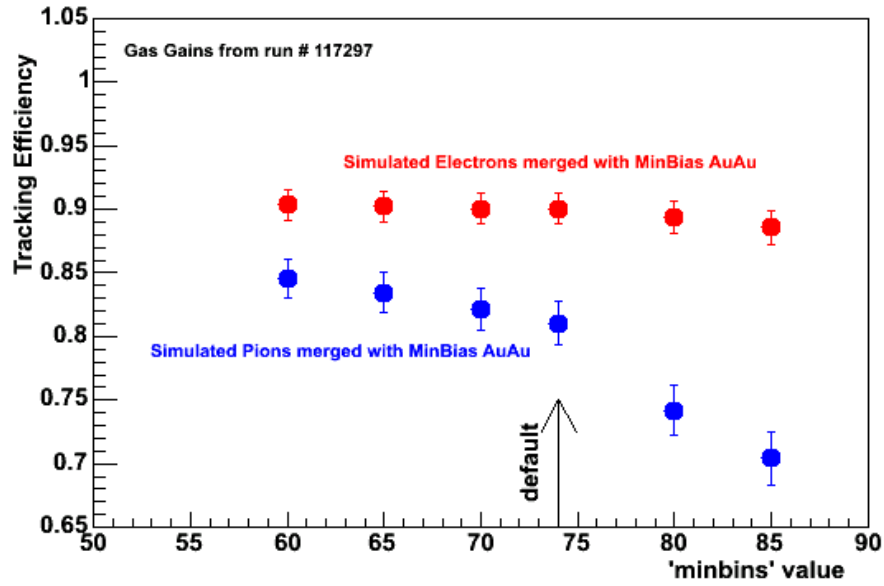

Fig. 10

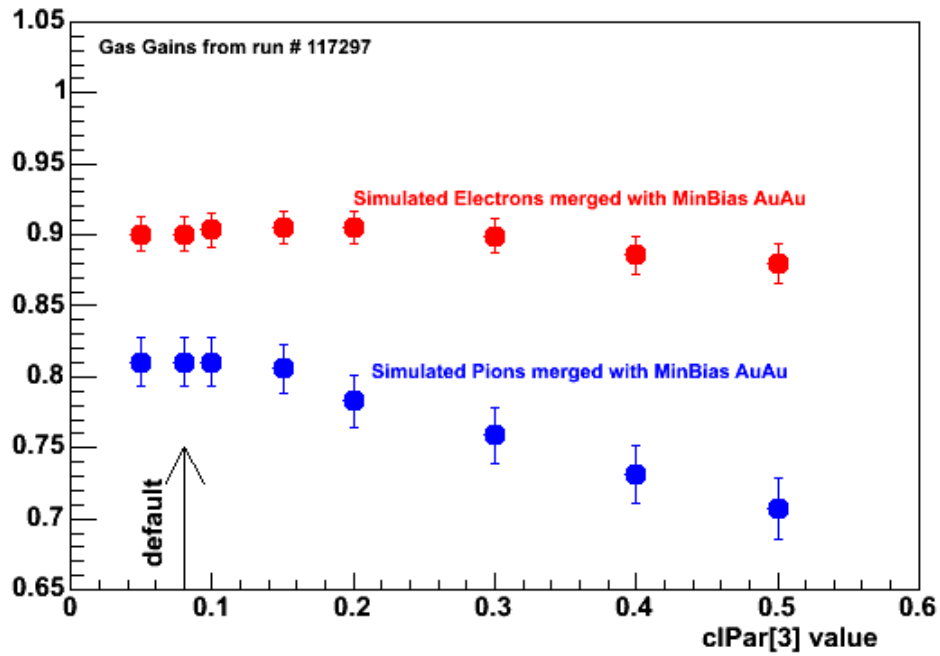Fig.11 below shows tracking efficiency vs **clPar[3]** parameter:

Fig. 11

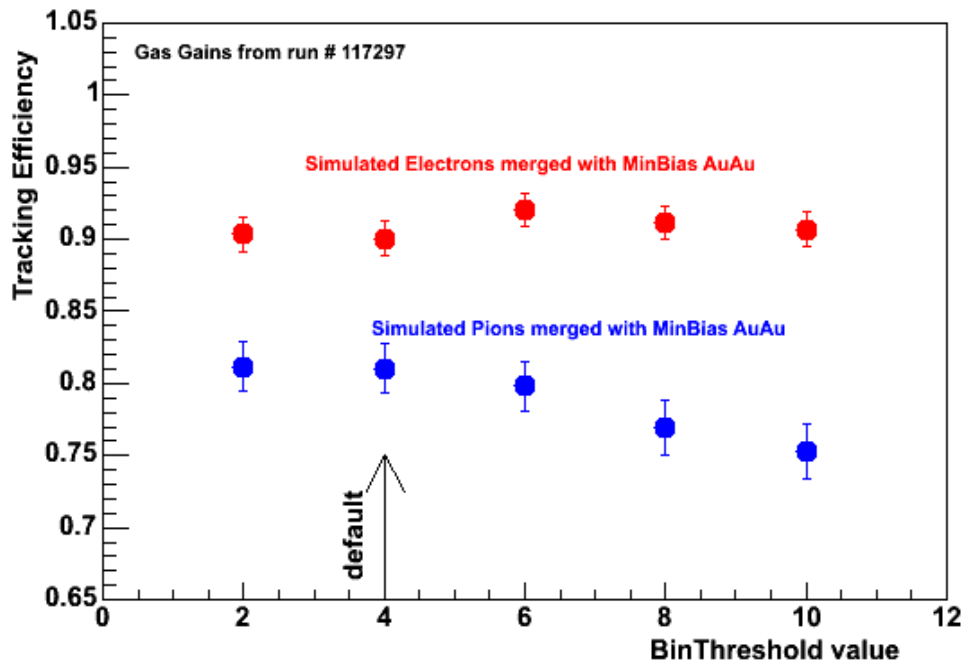Gif.12 shows tracking efficiency vs **clPar[5]** (BinThreshold) parameter:

Fig. 12

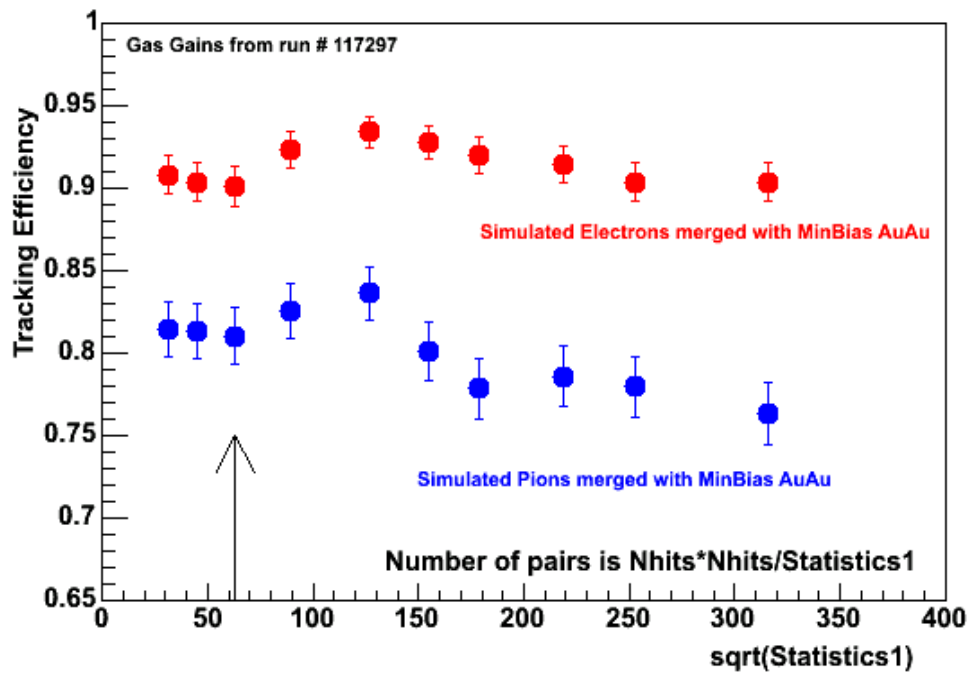The plot below shows tracking efficiency vs **Statistics1** parameter:

Fig. 13

In this plot points on the right side correspond to small number of hit pairs, the points on the left correspond to large number of hit pairs. As one can see, the distribution exibits a maximum at approximately ¼ of the default number of hit pairs. The efficiency increase takes place for high multiplicity events, and the increase is almost 10% for both electrons and pions. The reason for this behaviour is not understood.

Fig.14 shows change of tracking efficiency for electrons vs clustering parameters, clPar[0] and clPar[1]. When clusters (peaks) in two-dimensional Phi-Alpha histogram are searched for, bins with amplitude less than clPar[0] fraction of the maximum bin are rejected. A peak is accepted only if it is larger than clPar[1] fraction of the maximum bin. Clustering parameters are shown in percent in this plot. Default values are 5% for clPar[0] and 8% for clPar[1]. The numbers in the plot show change in number of reconstructed tracks out of total 665 tracks.
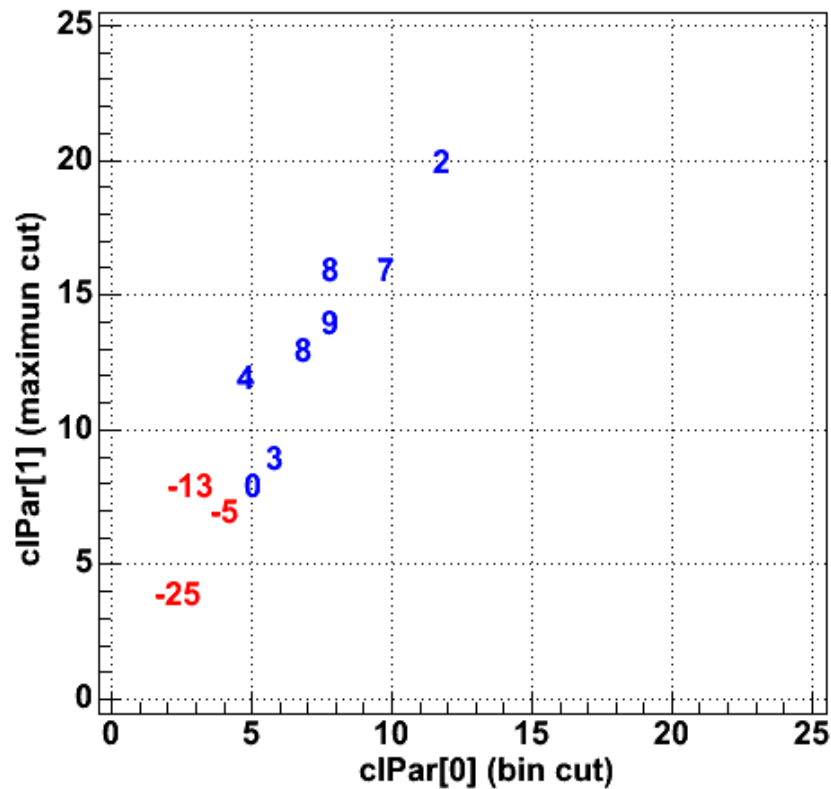

Fig.14

Tracking efficiency for electrons can be improved if clustering parameters are increased to 8% for clPar[0] and 14% for clPar[1]. But such increase in tracking efficiency for electrons will result in decresed tracking efficiency for pions, as can be seen from the following plot.

Fig.15 shows the same plot for pions. The numbers in the plot show the change in number of reconstructed tracks out of total 659 tracks.
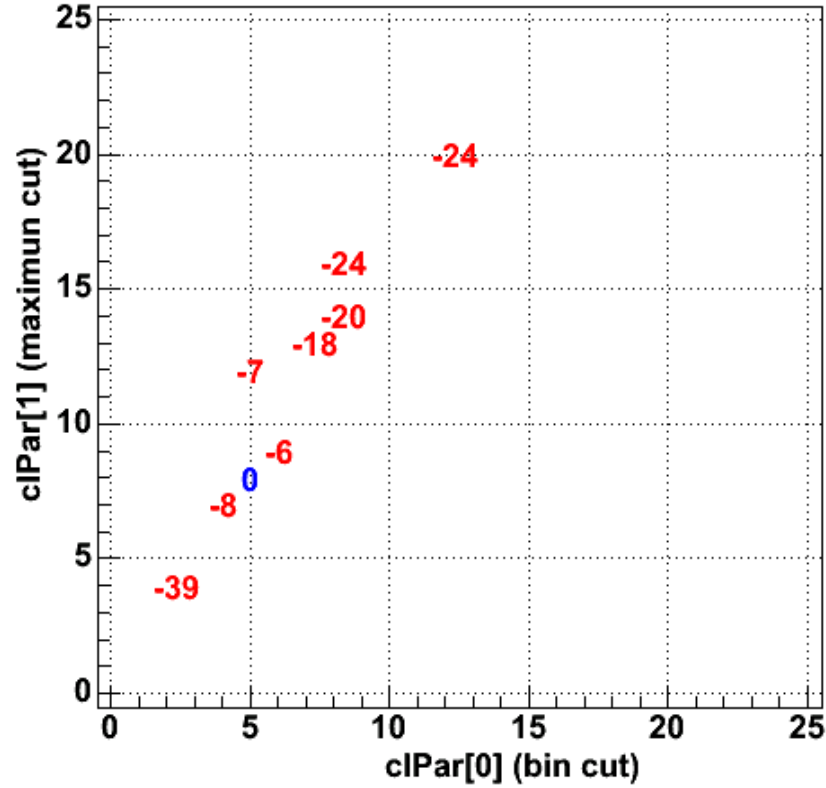

*Fig. 15*

6. Conclusions

Tracking parameters are almost optimal.

Number of hit pairs used in Hough Transform should be reduced by approximately factor of 4 (Statistics1 parameter increased 4 times). In addition to increased tracking efficiency, this will result in faster tracking.
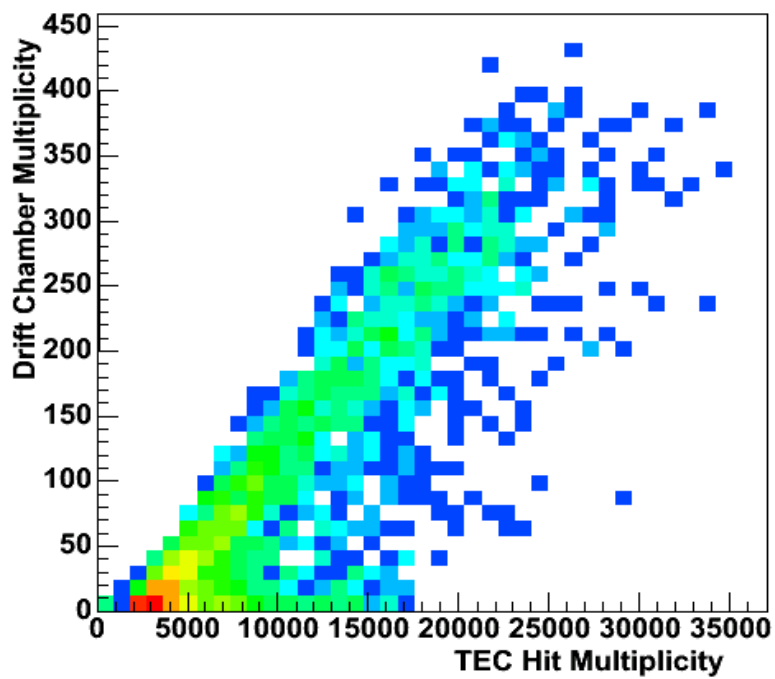
To increase tracking efficiency for electrons, one can increase clustering parameters clPar[0] and clPar[1] to 0.08 and 0.14 correspondingly. However, this will result in reduced tracking efficiency for pions.

Appendix A. Some useful plots

Drift Chamber multiplicity vs Tec track multiplicity:
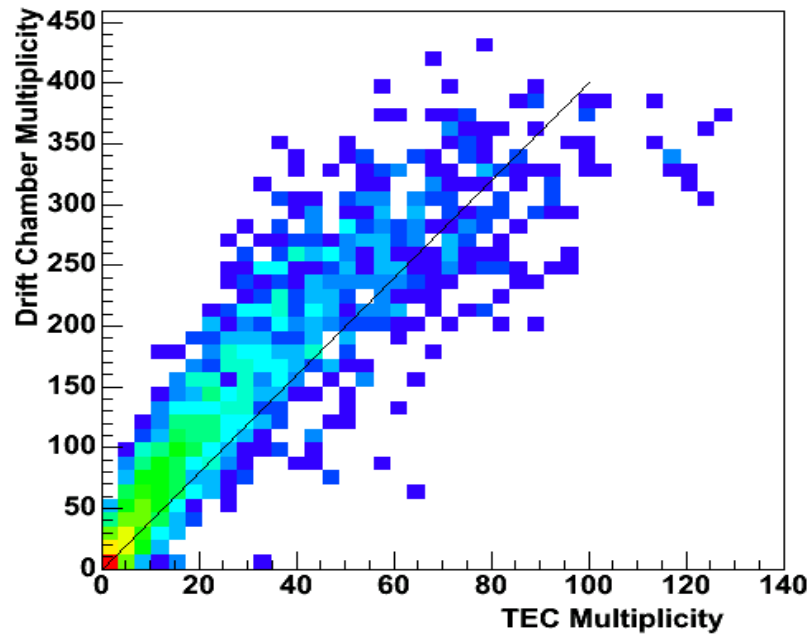
Drift Chamber multiplicity vs Tec hit multiplicity:

Tec track multiplicity vs Tec hit multiplicity: